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INFORMATION TRANSFER IN DISPLAY-CONTROL SYSTEMS

Short Computational Methods for and Validity of the DEI Technique

Prepared For

U.S. ARMY ELECTRONICS RESEARCH AND DEVELOPMENT LAB.

Fort Monmouth, New Jersey

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Applied Psychological Services

Wayne, Pennsylvania

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Information Transfer in Display-Control Systems

VII. Short Computational Methods for and Validity of the DEI Technique

Arthur I. Siegel
William Miehle
Philip Federman

prepared by

Applied Psychological Services
Wayne, Pennsylvania

for the

U. S. Army Electronics Research and Development Laboratory
Fort Monmouth, New Jersey

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PURPOSE

The over-all goal of the present program, conducted by Applied Psychological Services, is to develop a technique for evaluating the information transfer characteristics of displays in display reading→ operator decision making→ control action situations. The basis of the study is the present state of the art of Signal Corps' systems. The total program is composed of eight phases. These include:

Phase 1	Survey and development of a logic for evaluating display→operator decision making→control systems and mathematical expression of the logic
Phase 2	Development of the exponents for the mathematical expression
Phase 3	First verification of technique against outside criterion data
Phase 4	Application of the technique to additional representative Signal Corps' equipments and systems
Phase 5	Determination of the uniqueness of the factors included in the mathematical expression and appropriate modification of the technique
Phase 6	Study of additional factors which might enhance the validity, reliability, and utility of the technique
Phase 7	Preparation of a guide for users of the technique
Phase 8	Study of novel human information handling rates and other human factors engineering problems associated with Signal Corps' equipment and systems under research and development for the purpose of enhancing the utility of the displays and improving system effectiveness.

The work accomplished to date in achieving the requirements of Phases 1 through 7 has been reported in previous reports of this series. The current report presents the results of further work towards achieving the purposes subsumed under Phase 6. The report presents several short methods for computing the display evaluative index derived in the course of the present program and the results of a final study of the empirical validity of the technique.

ABSTRACT

Several short methods for computing the Display Evaluative Index (DEI) are first described. The first method eliminates the requirement for calculating the values for the three factors comprising the DEI. Although the method does not generally provide an exact value for the DEI, it does provide an approximate value. The method is similar to linear extrapolation and is exact to the extent that the fractional changes of the variables involved are small.

A second short computational method is presented which provides exact relative DEIs. This method uses fractional increments and is recommended for use in computing DEIs when: (1) only two or three variations of design are involved, and (2) the increments are known.

The third method employs a digital computer for computing DEIs.

The DEI was applied to several additional Signal Corps' systems and to hypothetical variations of these systems. The results of these applications again suggested that the technique possesses adequate evaluative sensitivity for distinguishing between various designs of the same system.

A final validity study indicated that the DEI possesses adequate empirical validity.

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PURPOSE AND SCOPE OF THE DISPLAY EVALUATIVE INDEX (DEI) TECHNIQUE

The purpose of the Display Evaluative Index (DEI) technique is to provide a quantitative measure of the effectiveness of a particular equipment design from the information transfer point of view. The technique is applicable to situations in which the system operator must act on information provided by the displays in a system. The basis of the equipment evaluation is one or more tasks performed by an equipment-operator combination. A task is essentially defined as an integrated unit of operator activity composed of a number of detailed operator actions. Different design variations may require the operator to perform different operations in order to achieve the same end result. For each application of the technique, the details of the operations must be known for each design variation. The same set of variations may give different DEI values for different task units.

Application of the index is limited to one operator equipments or to situations in which there is minimum interaction between operators. It is further assumed that the indicators and controls on the equipment meet minimal human factors design standards as set forth in various human factors engineering design guides. Thus, it is assumed that panel arrangements are reasonable, indicators are of approved types and sizes, force and torque requirements are met, directional expectancies are satisfied, etc. The DEI does <u>not</u> rate the electronic or mechanical reliability of the equipment nor does it consider maintainability. It does rate the information transfer effectiveness.

Although the DEI was designed to possess a range of values between 0 and 1 (1 being a perfect system), any individual DEI value possesses little interpretative significance. Comparison of any individual DEI value with the DEI values of alternative designs for the same system allows a choice of the best system from the points of view considered.

The present progress report presents several short approaches for calculating DEIs. Additionally, this report gives the results of additional application of the DEI technique to Signal Corps' systems. These systems are:

1. Radio Set AN/GRC-50
2. Radio Set AN/GRC-66
3. Radar Set AN/MPQ-29 (Operating Adjustments Task)
4. Radar Set AN/MPQ-29 (Target Acquisition and Radar Tracking Task)
5. Radar Set AN/TPS-33 (Starting, Tuning, and Orienting Equipment Task)
6. Radar Set AN/TPS-33 (Detection of Targets Task)

The report also presents the results of a study of the empirical validity of the DEI in its latest and complete form.

FACTUAL DATA II

SHORT COMPUTATIONAL METHODS

In the course of the present program, the DEI technique was first developed in preliminary form represented as:

$$DEI = A\,B^{1/2}C^{1/4}D^{1/3*}$$

$$\text{where } A = \frac{1}{1 + \Sigma w_i}$$

$$B = \left[\frac{(n+m)_u}{2N}\right] \cdot \left[\frac{(n+m)_u}{(n+m)_t}\right]$$

$$C = e^{-\sum_i (T - t_i) - \sum_k |M_k|}, \quad t_i < T_i$$

$$D = \frac{2}{Q + n_0}$$

and

A = complexity factor

B = directness factor

C = critical time and information mismatch factor

D = data transfer factor

M_k = mismatch (in digits) between elements connected by kth link

Q = actual number of indicator and control parts

n_0 = number of other elements (▷, ▷, □)

w = link weight

n = number of indicators

m = number of controls

N = number of forward links

$(n+m)_u$ = number of used indicators and controls connected to forward links

$(n+m)_t$ = total number of indicators and controls

T_i = minimum time required for subtask i

t_i = time allotted for subtask i

* Factor E, the cost factor, is ignored in this and the subsequent discussion.

Following an initial series of applications of the technique, a study was performed into the empirical validity of the technique. As a result of the positive indications of the empirical validity data, it was decided that the technique possessed sufficient merit to warrant further elaboration. Accordingly, an intercorrelational study was performed among the factors and the technique consolidated and expanded to include additional concepts. As a result of this effort, the DEI was set equal to:

$$\frac{(n+m)_u \sqrt[4]{R}}{(1+\Sigma w)\sqrt{N(n+m)_t(Q+n_0)}} \exp\left\{-\frac{1}{4}\left[\Sigma I\left(\frac{T}{T'}-1\right)+\frac{1}{16}\Sigma I\left(\frac{T}{T'}\right)^3+\frac{N_c}{10}+\Sigma\left|M\right|\right]\right\}$$

where:

w	=	link weight
n	=	number of indicators
m	=	number of controls
$(n+m)_u$	=	number of used indicators and controls
$(n+m)_t$	=	total number of indicators and controls
N	=	total number of information and instruction links
Q	=	actual number of indicator and control parts
n_0	=	number of other elements (▷, ▷, □)
i	=	information in digits associated with an indicator or control and associated with one transfer
ΣI	=	sum of i for all transfers in a subtask in digits

T = total time in seconds required for all transfers in a subtask

T' = total time in seconds allotted to a subtask

$\overline{R}$ = product of all utilization efficiency factors R

M = information mismatch between indicator and control in digits

N_c = number of critical links

Computation of DEI by the Logarithmic Differential Method

Since the computation of the DEI involves a number of arithmetic operations which may become tedious, a number of abbreviated computational techniques have been derived.

In the application of the DEI to several design variations, one of the variations may be used as a basis for comparison. It is usually easier and more accurate to use one variation as a reference and to describe the other variations in terms of changes in the reference design. For example, one design variation might possess three more "used" elements, two more weighted links, seven more parts (Q), and three tenths digits less mismatch than the reference variation. Heretofore, the total DEI was calculated for both the reference and the alternate design. In the method to be described, the approximate fractional change of the DEI is computed directly. The method is general and does not depend on the particular form of the DEI factors.

Application to the Original DEI

The old DEI was given by the following formula:

$$I' = A\,B^{1/2}C^{1/4}D^{1/3}$$

Taking the natural log of each side gives:

$$\ln I' = \ln A + \frac{1}{2}\ln B + \frac{1}{4}\ln C + \frac{1}{3}\ln D$$

Taking the differential of each side gives:

$$\frac{dI'}{I'} = \frac{dA}{A} + \frac{1}{2}\frac{dB}{B} + \frac{1}{4}\frac{dC}{C} + \frac{1}{3}\frac{dD}{D}$$

This is known as the logarithmic differential of I'. For small changes of A, B, C, and D, the radio $\frac{dI'}{I'}$ represents a good approximation for the actual fractional change of I'.

In the method to be described, A, B, C, and D will be expressed in terms of their variations before taking the differential. This gives:

$$\ln I' = \ln\frac{1}{1+w} + \frac{1}{2}\ln\frac{u^2}{2Nt} + \frac{1}{4}\ln e^{-(T+M)} + \frac{1}{3}\ln\frac{2}{Q+n_0}$$

where

$$w = \Sigma w_i,\ u = (n+m)_u,\ t = (n+m)_y,\ T = \Sigma(T_k - t_k),\ M = \Sigma|M_k .$$

Rewriting the above yields:

$$\ln I' = -\ln(1+w) + \ln u - \frac{1}{2}\ln N - \frac{1}{2}\ln t - \frac{1}{2}\ln 2 - \frac{1}{4}(T+M) + \frac{1}{3}\ln 2 - \frac{1}{3}\ln(Q+n_0)$$

Taking the differential we have:

$$\frac{dI'}{I'} = -\frac{dw}{1+w} + \frac{du}{u} - \frac{1}{2}\frac{dN}{N} - \frac{1}{2}\frac{dt}{t} - \frac{1}{4}(dT + dM) - \frac{1}{3}\frac{d(Q+n_0)}{(Q+n_0)}$$

Here, dw is the change (increment) in w relative to the reference variation. If w is greater by two over the reference variation, then dw = 2. If w is three less than the w of the reference variation, then dw = -3.

Note that the value of I' need not be calculated for any variation. If it is known, then the I' value of the present variation can be calculated by $I' \left(1 + \frac{dI'}{I'}\right)$, where I' is the reference value. In other words, dI' is the change (positive or negative) in the value of I' corresponding to changes of the variables of the DEI.

The following example employing the plotting and tracking task and equipment variations for the AN/FPS-56 radar described in the fourth quarterly report of this series (Siegel, Miehle, and Federman, 1962) illustrates the method. The original equipment design is used as the reference design and the previously described hypothetical "variation 3" is employed as the comparison design.

Variation O is used as reference

1 + w	=	145	t	=	16
u	=	13	M	=	.6
N	=	16	T	=	0
$Q + n_0$	=	17	(I'	=	.0169)

Variation 3

dw	=	-.5	dt	=	2
du	=	1	dM	=	0
dN	=	0	dT	=	0
			$d(Q + n_0)$	=	2

$$\frac{dI'}{I'} = -\frac{-.5}{14.5} + \frac{1}{13} - \frac{1}{2}\left(\frac{2}{16}\right) - \frac{1}{3}\left(\frac{2}{17}\right)$$

$$= .0345 + .0769 - .0625 - .0392 = .0097$$

$$I'_2 = I'_0\left(1 + \frac{dI'}{I'}\right) = .0167\,(1 + .0097) = .0169$$

This DEI value of .0169 for variation 3 is exactly the same as the value which was previously computed by employing the total calculation.

For variations differing more widely from the reference, the approximate values usually may be expected to differ from the calculated DEI by a larger amount.

This short method was applied in two different ways to variations of six systems and tasks and gave rankings in agreement with direct calculation of the DEI. In case 1, the "original" system design was used as the reference and in case 2 the "best" design, as indicated by the DEI, was used as the reference design. In the latter case, naturally all $\frac{dI}{I}$ values were negative. Ranking is preserved despite the fact that for "poor" equipment designs, as indicated by the DEI, $\frac{dI}{I}$ becomes less than -1 and therefore becomes useless in computing I' values. However, since the design engineer is generally interested in pinpointing the best design, it is of little interest actually to compute the I' value for a poorer design.

It is stressed that $\frac{dI'}{I'}$ is not the exact value of the fractional change in I'. The method is similar to linear extrapolation and is exact only to the extent that the fractional changes of variables are "small." In cases in which two large terms of opposite signs sum to zero, the accuracy of the method is further suspect.

It is recommended that the system which is guessed as being best (before applying the DEI) be used for the reference so that the incremental values of I' for better systems as indicated by the DEI will be more accurate.

Table 1 presents the rank order of the variations, the approximate $\frac{dI'}{I'}$, and the I' values when the original design was chosen as the reference for comparison with a number of hypothetical equipment variations. Table 2 shows the results when the "best" variation was chosen as the reference. In each case the results of ranking agrees with that obtained by employing the direct method.

Application of the Logarithmic Differential Method to the New DEI

The formula for the DEI in its latest form and without the cost factor is:

$$A\,P^{1/2}S^{1/4} =$$

$$= \frac{(n+m)_u \sqrt[4]{\overline{R}}}{(1+\Sigma w)\sqrt{N(n+m)_t(Q+n_0)}} \exp\left\{-\frac{1}{4}\left[\Sigma I\left(\frac{T}{T'}-1\right)+\frac{1}{16}\Sigma I\left(\frac{T}{T'}\right)^3+\frac{N_c}{10}+\Sigma|M|\right]\right\}$$

Taking the natural log of each side:

$$\ln I' = \ln(n+m)_u + \frac{1}{4}\ln\overline{R} - \ln(1+\Sigma w) - \frac{1}{2}\ln N - \frac{1}{2}\ln(m+m)_t$$
$$- \frac{1}{2}\ln(Q+n_0) - \frac{1}{4}\left[\Sigma I\left(\frac{T}{T'}-1\right)+\frac{1}{16}\Sigma I\left(\frac{T}{T'}\right)^3+\frac{N_c}{10}+\Sigma|M|\right]$$

Taking the differential of each side:

$$\frac{dI'}{I'} = \frac{d(n+m)_u}{(n+m)_u} + \frac{1}{4}\frac{d\overline{R}}{\overline{R}} - \frac{d(\Sigma w)}{1+\Sigma w} - \frac{1}{2}\frac{dN}{N} - \frac{1}{2}\frac{d(n+m)_t}{(n+m)_t} - \frac{1}{2}\frac{d(Q+n_0)}{Q+n_0}$$
$$- \frac{1}{4}\left\{d\left[\Sigma I\left(\frac{T}{T'}-1\right)\right] + d\left[\Sigma|M|\right]\right\} - \frac{1}{64}\,d\left[\Sigma I\left(\frac{T}{T'}\right)^3\right] - \frac{1}{40}\,dN_c$$

Table 1

Comparison of Direct and Short Calculational Results for the Old DEI Using Original Design (Variation O) as the Reference Design

	Variation	$\frac{dI'}{I'}$	Approximate I'	Direct I'	Rank Order
AN/FPS-56	O	0	.01670	.0167	4
(Plotting and Tracking)	1	.1140	.01885	.0186	2
	2	.2005	.02010	.0207	1
	3	.0097	.01690	.0169	3
	4	-.8340	.00290	.0074	5
AN/FPS-56	O	0	.00770	.00770	2
(Target Definition)	1	.2295	.00945	.01010	1
	2	-.0340	.00740	.00741	3
	3	-.5470	.00350	.00445	5
	4	-.0672	.00718	.00710	4
AN/FPS-56	O	0	.00487	.00487	2
(Target Ranging)	1	.2260	.00596	.00637	1
	2	-.0578	.00459	.00460	3
	3	-.2170	.00381	.00393	5
	4	-.1640	.00408	.00420	4
AN/UIH-3	O	0	.00976	.00976	4
(Public Address Set)	1	.216	.01178	.01250	2
	2	.488	.01450	.01760	1
	3	-.416	.00570	.00762	5
	4	.142	.01120	.01130	3
APS-251	O	0	.000220	.000220	3
(Target Assignment)	1	.133	.000250	.000260	2
	2	-1.637	*	.000085	4
	3	.819	.000400	.000491	1
AN/MPQ-4A	O	0	.00470	.00470	3
	1	-.393	.00285	.00341	4
	2	.248	.00587	.00615	2
	3	.360	.00640	.00708	1
	4	-.512	.00230	.00330	5

* Meaningless

Table 2

Comparison of Direct and Short Calculational Results for the Old DEI Using the "Best" Design Variation as the Reference Design

	Variation	$\frac{dI'}{I'}$	Approximate I'	Direct I'	Rank Order
AN/FPS-56	O	-.270	.0151	.0167	4
(Plotting and Tracking)	1	-.130	.0181	.0186	2
	† 2	0	.0207	.0207	1
	3	-.215	.0163	.0169	3
	4	-1.119	*	.0074	5
AN/FPS-56	O	-.317	.00690	.00770	2
(Target Definition)	† 1	0	.01010	.01010	1
	2	-.389	.00618	.00740	3
	3	-.876	**	.00445	5
	4	-.441	.00565	.00710	4
AN/FPS-56	O	-.317	.00435	.00487	2
(Target Ranging)	† 1	0	.00637	.00637	1
	2	-.412	.00375	.00460	3
	3	-.547	**	.00395	5
	4	-.543	**	.00420	4
AN/UIH-3	O	-.736	**	.00976	4
(Public Address Set)	1	-.365	.0112	.01250	2
	† 2	0	.0176	.01760	1
	3	-.980	**	.00762	5
	4	-.594	**	.01130	3
APS-251	O	-2.20	*	.000220	3
(Target Assignment)	1	-1.99	*	.000260	2
	2	-4.90	*	.000085	4
	† 3	0	.000491	.000491	1
AN/MPQ-4A	O	-.466	.00378	.00470	3
	1	-1.017	*	.00341	4
	2	-.157	.00597	.00615	2
	† 3	0	.00708	.00708	1
	4	-1.121	*	.00330	5

* Meaningless
** Inaccurate
† Reference Design

Any further differentiation of sum and product terms is not advisable since it would only increase the number of terms.

From the equation, it is seen that I' improves ($dI' > 0$) when the following increase: $(n + m)_u$ and $\overline{R}$, and when the following decrease: Σw, N, $(n + m)_t$ $(Q + n_0)$, $\Sigma I \left(\frac{T}{T'} - 1\right)$, $\Sigma I \left(\frac{T}{T'}\right)^3$, $\Sigma|M|$, and N_c. For variations of the same system and task a constraint will exist between the variables so that the changes will be related. Stated alternatively, it would not be possible to change each variable by itself without affecting some other variable or variables. This is a partial reason for some correlation among factors of the DEI for design variations within a task, despite the independence of the factors for arbitrarily chosen unrelated designs.

The logarithmic differential method (for the new DEI) was applied to a series of tasks and equipments for which DEI values were previously computed by the direct method. The first set of calculations (Table 3) used the original equipment design, variation O, as the reference. The second set (Table 4) employed the "best" design variation (highest DEI value) as the reference design. When the best design variation is used as the reference, the other variations necessarily will have a negative $\frac{dI'}{I'}$ value and the worst variation may even have a value of less than -1. The absolute value is not meaningful in such a case (when $\frac{dI'}{I'}$ approaches -1) but relative values still give the same rank order for each design considered.

An inspection of Tables 3 and 4 shows that in all but one case (APS-251, Table 4) the rank order calculated employing $\frac{dI'}{I'}$ agrees with that of the direct (exact) DEI calculational method.

Table 3

Comparison of Direct and Short Calculational Results for the Final DEI Using Original Design (Variation O) as the Reference Design

	Variation	$\frac{dI'}{I'}$	Approximate I'	Direct I'	Rank Order
AN/FPS-56	O	0	.00638	.00638	3
(Plotting and Tracking)	1	.059	.00676	.00675	2
	2	.588	.01013	.01294	1
	3	-.130	.00555	.00564	5
	4	-.085	.00584	.00587	4
AN/FPS-56	O	0	.00479	.00479	2
(Target Definition)	1	.265	.00606	.00647	1
	2	-.132	.00416	.00420	4
	3	-.581	.00201	.00270	5
	4	-.081	.00440	.00431	3
AN/FPS-56	O	0	.00306	.00306	2
(Target Ranging)	1	.265	.00387	.00418	1
	2	-.130	.00266	.00272	3
	3	-.242	.00232	.00240	5
	4	-.189	.00248	.00259	4
AN/UIH-3	O	0	.00381	.00381	4
(Public Address Set)	1	.339	.00510	.00575	2
	2	.654	.00630	.00776	1
	3	-.033	.00368	.00370	5
	4	.200	.00457	.00436	3
APS-251	O	0	.000371	.000371	3
(Target Assignment)	1	.071	.000397	.000591	2
	2	-2.443	*	.000104	4
	3	1.341	.000869	.001402	1
AN/MPQ-4A	O	0	.00220	.00220	3
	1	-.203	.00175	.00185	4
	2	.328	.00292	.00314	2
	3	.528	.00336	.00391	1
	4	-.619	.00084	.00137	5

Table 4

Comparison of Direct and Short Calculational Results for the Final DEI Using the "Best" Design Variations as the Reference Design

	Variation	$\frac{dI'}{I'}$	Approximate I'	Direct I'	Rank Order
AN-FPS-56	O	-.866	**	.00638	3
(Plotting and Tracking)	1	-.770	**	.00675	2
	†2	0	.01294	.01294	1
	3	-1.018	*	.00564	5
	4	-1.004	*	.00587	4
AN/FPS-56	O	-.359	.00415	.00479	2
(Target Definition)	†1	0	.00647	.00647	1
	2	-.525	.00307	.00420	4
	3	-.942	**	.00270	5
	4	-.502	.00322	.00431	3
FPS-56	O	-.359	.00268	.00306	2
(Target Ranging)	†1	0	.00418	.00418	1
	2	-.523	.00199	.00272	3
	3	-.615	**	.00240	5
	4	-.616	**	.00259	4
AN/UIH-3	O	-.955	**	.00381	4
(Public Address Set)	1	-.374	.00486	.00575	2
	†2	0	.00776	.00776	1
	3	-.970	**	.00370	5
	4	-.755	**	.00436	3
APS-251	O	-1.630	*	.000370	3
(Target Assignment)	1	-1.123	*	.000591	2
	2	-6.822	*	.000104	4
	†3	0	.001402	.001402	1
AN/MPQ-4A	O	-.646	**	.00220	3
	1	-.914	**	.00185	4
	2	-.242	.00296	.00314	2
	†3	0	.00391	.00391	1
	4	-1.391	*	.00137	5

* Meaningless
** Inaccurate
† Reference Design

Computation of Exact Relative DEIs by Fractional Increment Method

A second short method for calculating the DEI has also been developed. This method gives the ratio of DEI values for a given design variation to that of a reference variation directly without calculating the individual DEI values. The variations are then ranked in the order of decreasing ratios. The ratio for the reference variation is obviously one without computation.

Let:

$$(n + m)_u = a$$

$$R = b$$

$$1 + \Sigma w = c$$

$$N = d$$

$$(n + m)_t = g$$

$$Q + n_0 = h$$

$$\frac{1}{4}\left[\Sigma I\left(\frac{T}{T'} - 1\right) + \frac{1}{16}\Sigma I\left(\frac{T}{T'}\right)^3 \Sigma|M| + \frac{N_c}{10}\right] = k$$

The DEI may be given by:

$$I' = \frac{a\sqrt[4]{b}\ e^{-k}}{c\sqrt{d}\ \sqrt{g}\ \sqrt{h}}$$

For the reference variation $I' = I'_r = \dfrac{a_r\sqrt[4]{b_r}\ e^{-k_r}}{c_r\sqrt{d_r}\ \sqrt{g_r}\ \sqrt{h_r}}$

For a given design, let $a = a_r + \Delta a$, $b = b_r + \Delta b$, etc., where Δa is the change in a for a given variation. Thus, if $a_r = 15$ and $a = 13$, then $\Delta a = -2$, or if $b_r = .89$ and $b = .95$, then $\Delta b = .06$. Therefore:

$$I' = \frac{(a_r + \Delta a)\sqrt[4]{(b_r + \Delta b)}\ e^{-(k_r + \Delta k)}}{(c_r + \Delta c)\sqrt{d_r + \Delta d}\ \sqrt{g_r + \Delta g}\ \sqrt{h_r + \Delta h}}$$

Rewriting:

$$I' = \frac{a_r\left(1 + \frac{\Delta a}{a_r}\right) \sqrt[4]{b_r} \sqrt[4]{1 + \frac{\Delta b}{b_r}}\ e^{-k_r}\ e^{-\Delta k}}{c_r\left(1 + \frac{\Delta c}{c_r}\right)\sqrt{d_r}\sqrt{1 + \frac{\Delta d}{d_r}}\sqrt{g_r}\sqrt{1 + \frac{\Delta g}{g_r}}\sqrt{h_r}\sqrt{1 + \frac{\Delta h}{h_r}}}$$

$$= \frac{a_r \sqrt[4]{b_r}\ e^{-k_r}}{c_r\sqrt{d_r}\sqrt{g_r}\sqrt{h_r}} \cdot \frac{\left(1 + \frac{\Delta a}{a_r}\right)\sqrt[4]{1 + \frac{\Delta b}{b_r}}\ e^{-\Delta k}}{\left(1 + \frac{\Delta c}{c_r}\right)\sqrt{1 + \frac{\Delta d}{d_r}}\sqrt{1 + \frac{\Delta g}{g_r}}\sqrt{1 + \frac{\Delta h}{h_r}}}$$

$$= I'_r\left[\frac{\left(1 + \frac{\Delta a}{a_r}\right)\sqrt[4]{1 + \frac{\Delta b}{b_r}}\ e^{-\Delta k}}{\left(1 + \frac{\Delta c}{c_r}\right)\sqrt{1 + \frac{\Delta d}{d_r}}\sqrt{1 + \frac{\Delta g}{g_r}}\sqrt{1 + \frac{\Delta h}{h_r}}}\right]$$

Therefore:

$$\frac{I'}{I'_r} = \frac{I'_r + \Delta I'}{I'_r} = 1 + \frac{\Delta I'}{I'_r} = \frac{\left(1 + \frac{\Delta a}{a_r}\right)\sqrt[4]{1 + \frac{\Delta b}{b_r}}\ e^{-\Delta k}}{\left(1 + \frac{\Delta c}{c_r}\right)\sqrt{1 + \frac{\Delta d}{d_r}}\sqrt{1 + \frac{\Delta g}{g_r}}\sqrt{1 + \frac{\Delta h}{h_r}}}$$

The ratio $\frac{I'}{I'_r}$ is thus expressed as a function of fractional increments of the factors and the increment of k.

This method of computation has compensating advantages when two conditions hold. The first is when there are only two or three variations. Then only one-half or two-thirds of the number of calculations must be performed. This saving more than compensates for the extra computations in obtaining $1 + \frac{\Delta a}{a}$, etc. The second is when the increments are directly known.

Rewriting:

$$I' = \frac{a_r\left(1+\frac{\Delta a}{a_r}\right)\sqrt[4]{b_r}\ \sqrt[4]{1+\frac{\Delta b}{b_r}}\ e^{-k_r}\ e^{-\Delta k}}{c_r\left(1+\frac{\Delta c}{c_r}\right)\sqrt{d_r}\ \sqrt{1+\frac{\Delta d}{d_r}}\sqrt{g_r}\ \sqrt{1+\frac{\Delta g}{g_r}}\sqrt{h_r}\ \sqrt{1+\frac{\Delta h}{h_r}}}$$

$$= \frac{a_r\ \sqrt[4]{b_r}\ e^{-k_r}}{c_r\sqrt{d_r}\sqrt{g_r}\sqrt{h_r}} \cdot \frac{\left(1+\frac{\Delta a}{a_r}\right)\sqrt[4]{1+\frac{\Delta b}{b_r}}\ e^{-\Delta k}}{\left(1+\frac{\Delta c}{c_r}\right)\sqrt{1+\frac{\Delta d}{d_r}}\ \sqrt{1+\frac{\Delta g}{g_r}}\sqrt{1+\frac{\Delta h}{h_r}}}$$

$$= I'_r\left[\frac{\left(1+\frac{\Delta a}{a_r}\right)\sqrt[4]{1+\frac{\Delta b}{b_r}}\ e^{-\Delta k}}{\left(1+\frac{\Delta c}{c_r}\right)\sqrt{1+\frac{\Delta d}{d_r}}\sqrt{1+\frac{\Delta g}{g_r}}\sqrt{1+\frac{\Delta h}{h_r}}}\right]$$

Therefore:

$$\frac{I'}{I'_r} = \frac{I'_r+\Delta I'}{I'_r} = 1+\frac{\Delta I'}{I'_r} = \frac{\left(1+\frac{\Delta a}{a_r}\right)\sqrt[4]{1+\frac{\Delta b}{b_r}}\ e^{-\Delta k}}{\left(1+\frac{\Delta c}{c_r}\right)\sqrt{1+\frac{\Delta d}{d_r}}\sqrt{1+\frac{\Delta g}{g_r}}\sqrt{1+\frac{\Delta h}{h_r}}}$$

The ratio $\frac{I'}{I'_r}$ is thus expressed as a function of fractional increments of the factors and the increment of k.

This method of computation has compensating advantages when two conditions hold. The first is when there are only two or three variations. Then only one-half or two-thirds of the number of calculations must be performed. This saving more than compensates for the extra computations in obtaining $1 + \frac{\Delta a}{a}$, etc. The second is when the increments are directly known.

In most cases there is a slight additional advantage in that $1 + \frac{\Delta a}{a}$, etc., is close to one, making table entry errors for roots unlikely. The possibility also exists of using the approximations $\sqrt[n]{1 + \frac{\Delta x}{x}} = 1 + \frac{1}{n}\frac{\Delta x}{x}$. Thus,

$$\frac{1}{\sqrt{1 + \frac{\Delta d}{d_r}}} \simeq 1 - \frac{1}{2}\frac{\Delta d}{d_r}$$

and

$$\sqrt[4]{1 + \frac{\Delta b}{b_r}} \simeq 1 + \frac{1}{4}\frac{\Delta b}{b_r}$$

The logarithmic differential method is in turn an approximation of this approximation. $\frac{I'}{I'_r}$ can be expressed as an approximation as follows:

$$\frac{I'}{I'_r} = (1 + \frac{\Delta a}{a})(1 + \frac{1}{4}\frac{\Delta b}{b_r})(1 - \Delta k)(1 - \frac{\Delta c}{c_r})(1 - \frac{1}{2}\frac{\Delta d}{d_r})(1 - \frac{1}{2}\frac{\Delta g}{g_r})(1 - \frac{1}{2}\frac{\Delta h}{h_r})$$

$$\frac{I'}{I'_r} = 1 + \frac{\Delta a}{a} + \frac{1}{4}\frac{\Delta b}{b_r} - \Delta k - \frac{\Delta c}{c_r} - \frac{1}{2}\frac{\Delta d}{d_r} - \frac{\Delta g}{g_r} - \frac{\Delta h}{h_r} - \ldots$$

$$+ \frac{1}{4}\frac{a}{a_r}\frac{\Delta b}{b_r} - \frac{a}{a_r}\Delta k - \frac{\Delta a}{a_r}\frac{\Delta c}{c_r} - \frac{1}{2}\frac{\Delta a}{a}\frac{\Delta d}{d} - \ldots$$

$$- \frac{1}{4}\frac{\Delta b}{b_r}\Delta k - \frac{1}{4}\frac{\Delta b}{b_r}\frac{\Delta c}{c_r}$$

+ sum of all triple products of $\frac{\Delta x}{x}$ terms

+ sum of all quadruple products + ...

$$- \frac{1}{32} \frac{\Delta a}{a_r} \frac{\Delta b}{b_r} \Delta k \frac{\Delta c}{\Delta c_r} \frac{\Delta d}{\Delta d_r} \frac{\Delta g}{\Delta g_r} \frac{\Delta h}{h_r} = 1 + \frac{\Delta I'}{I'}$$

If all product terms are neglected, then the result is identical with $1 + \frac{dI}{I}$.

FACTUAL DATA III

COMPUTER COMPUTATION OF THE DEI

A high speed digital computer can be employed to obtain most of the DEI variables and to calculate the DEI itself. Employment of this technique would not relieve the analyst of the requirement of drawing a transfer chart and supplying the following computer input information:

1. a list of the equipment indicators, their connections to or from links, and the amount of information associated with each link

2. a list of the equipment controls, their connections to or from links, and the amount of information associated with each link

3. a list of the complex process "boxes," their connections to or from links and the information associated with each link

4. a list of other elements (such as ▷ and ▷) and their connections to or from links

5. a list of time critical transfers and time allotted

6. the number of critical transfers, N_c

The computer is programmed to generate link blocks, to determine link types (information, instruction, corroborative) and link weights, and to calculate mismatches, actual time taken for a time critical transfer (T), total information (I) in a time critical transfer, utilization efficiency ($\bar{R}$), number of used indicators and controls $(n + m)_u$, total number of indicators and controls $(n + m)_t$, number of "other elements" (n_0), number of links (N), total number of parts (Q), and finally the value of the DEI.

$$I' = \frac{(n + m)_u \sqrt[4]{\overline{R}}}{(1 + \Sigma w)\sqrt{N(n + m)_t (Q + n_0)}} \exp\left\{-\left[\frac{1}{4} \Sigma I \left(\frac{T}{T'} - 1\right) + \frac{1}{16} \Sigma I \left(\frac{T}{T'}\right)^3 + \frac{N_c}{10} + \Sigma |M|\right]\right\}$$

A program analysis is shown in Figure 1. The DEI analyst must assign information values to all links associated with system indicators and controls and with complex process boxes. If certain values are not known, suitable pseudo-data are supplied to create zero mismatch for these links. This also holds for enabling links which are assigned zero information. The computer will calculate the information associated with other links.

The logical flow chart presented as Figure 1 is in general form and may be used as the basis for programming almost any digital computer. The following terms are used:

entry - smallest entity of information, e.g., link number, number of states, number of parts, type of block

block - a set of entries relating to one object, e.g., indicator block, link block

The program requires the following input data:

Indicator Block

1. identification number for each indicator
2. identification of each link FROM each indicator and the associated number of digits
3. identification of each link TO each indicator and the associated number of digits
4. number of parts

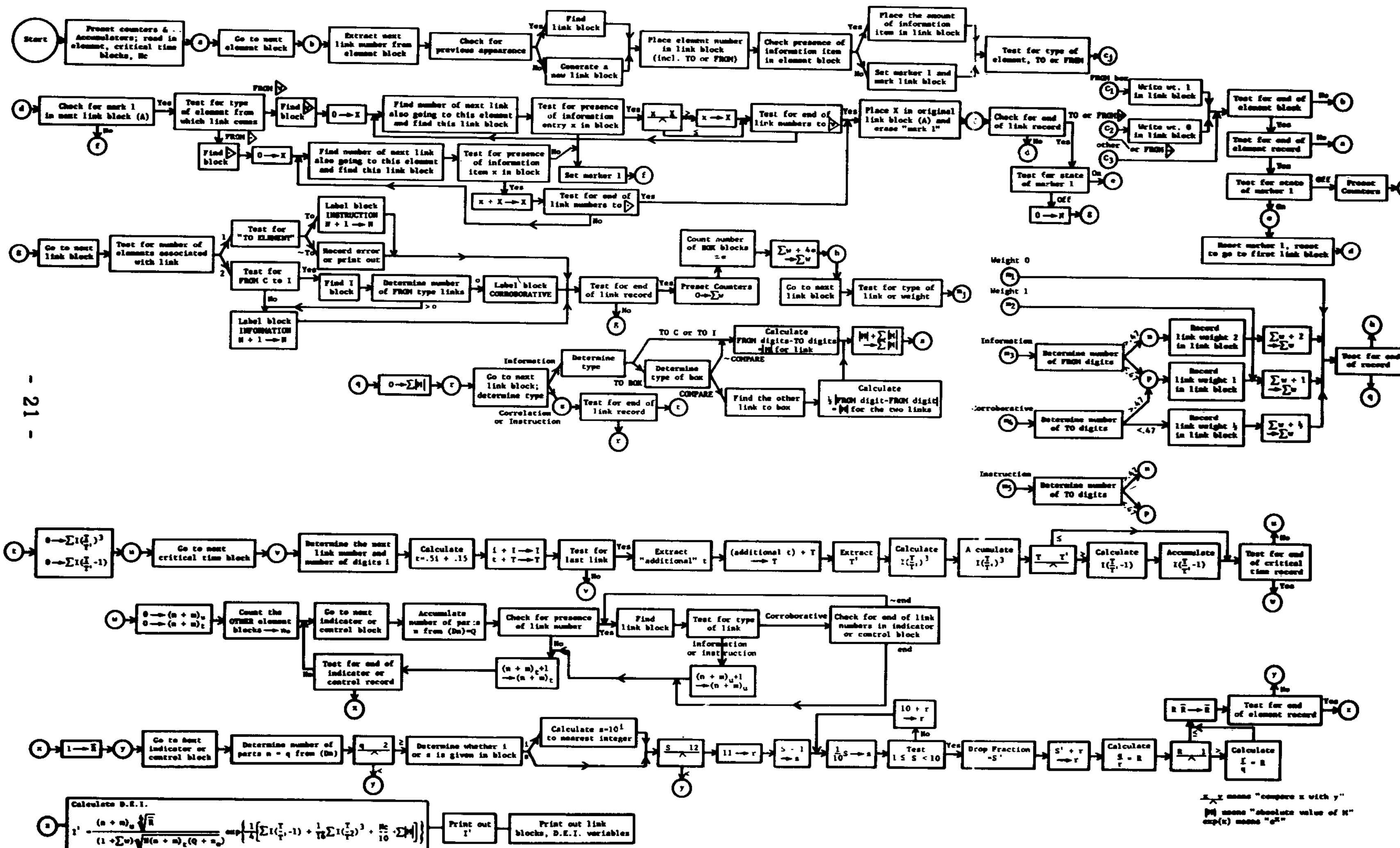

Figure 1 Flow chart for computer calculation of DEI

Control Block

1. identification number for each control

2. identification of each link FROM each indicator and the associated number of digits

3. identification of each link TO each indicator and the associated number of digits

4. number of parts

"Other" Element Block

1. identification number for each "other" element and its type (and, or, etc.)

2. identification of links FROM each complex process "box" and the number of states or digits

3. identification of each link TO each complex process "box" and the number of states or digits

Critical Time Block

1. number for each subtask

2. first and final link numbers and digits

3. other time needed (if blocks are involved)

4. time allotted (T')

Critical Links

1. number

Operating on these input data the computer will calculate and print-out intermediate data values and the calculated DEI value for a given equipment design in accordance with the logic of Figure 1. Intermediate variables calculated are:

1. Σw
2. N
3. Q
4. n_0
5. $(n + m)_u$
6. $(n + m)_t$
7. $\overline{R}$
8. $\Sigma |M|$
9. $\Sigma I \left(\frac{T}{T'} - 1\right)$
10. $\Sigma I \left(\frac{T}{T'}\right)^3$

It will be noted that the method of organizing the input data allows for equipment design change of an individual indicator, control or operator subtask without affecting other input data. Thus, by arranging each task set of input data on a separate control deck, various proposed design changes can be quickly inserted while holding the rest of the design constant and the effects of the design change on the DEI calculated in a matter of minutes.

FACTUAL DATA IV

APPLICATION TO TWO ADDITIONAL SYSTEMS

The DEI, in its revised and perfected form, has been applied to two other Signal Corps' systems. These two field system applications which have not been previously reported involve the radar sets AN/MPQ-29 and AN/TPS-33.

Radar Set AN/MPQ-29

The radar set AN/MPQ-29 (Figure 2) is a mobile tracking and plotting system designed to search for, track, and plot the course of airborne targets. The equipment may also be used to guide aircraft for reconnaissance purposes. Radar information is displayed on two cathode-ray tubes, the plan position indicator scope and the J scope. The operator's tasks have been analyzed in terms of two different and specific aspects: (1) operating adjustments, and (2) target acquisition and radar tracking.

The operating adjustments usually take place before employing the equipment for tactical operation. Settings are checked on the various operating controls and reset as necessary for both optimal receiving and transmitting.

The equipment is capable of operating in several target acquisition modes: i.e., search, azimuth sector scan, radar deadman control, and target selector. For purposes of the DEI applications, only operator tasks involved in the search mode were considered. In this mode the scanner rotates through 360° of azimuth and the elevation of the scanner can be controlled either manually or automatically.

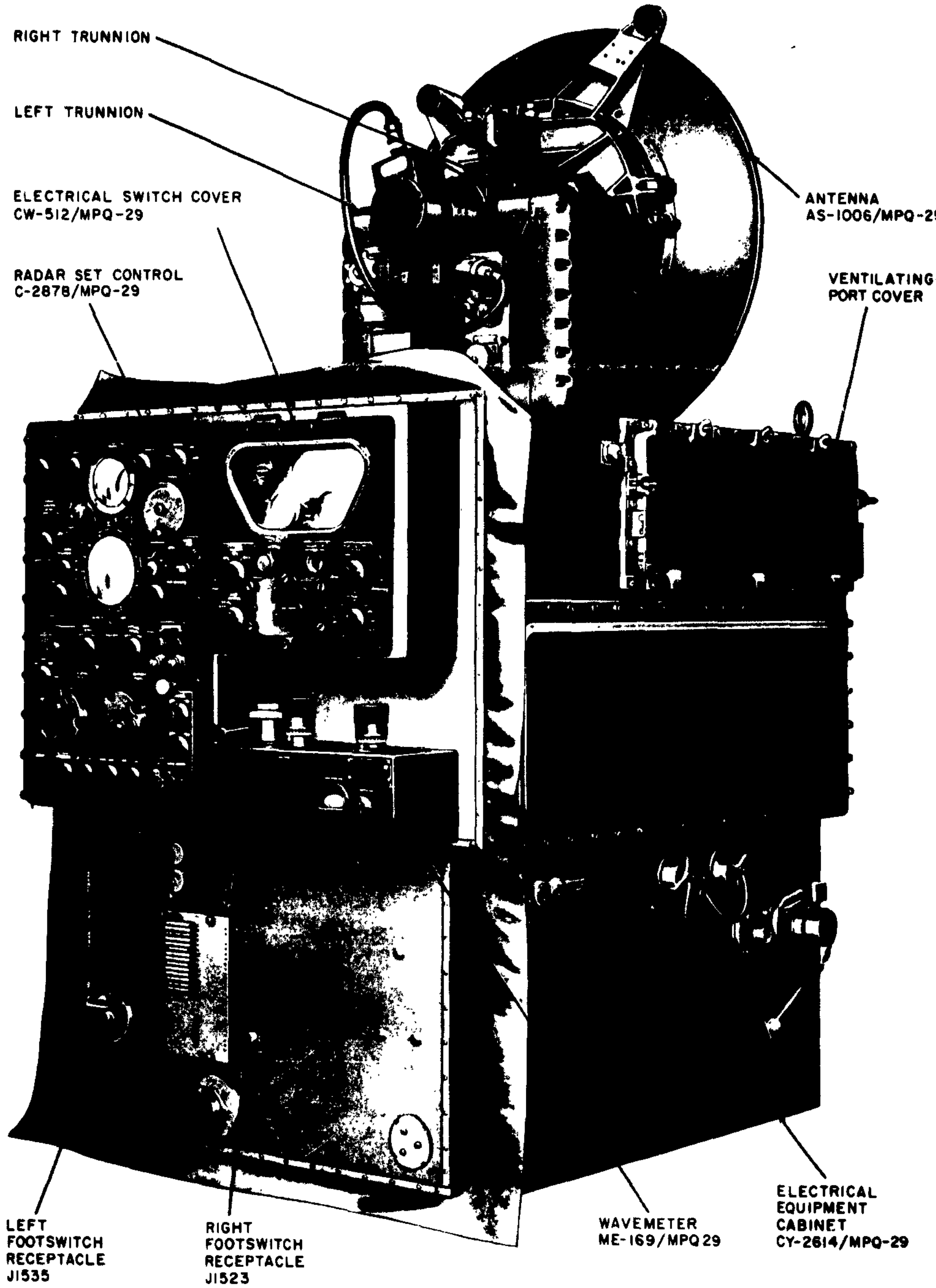

Figure 2 Radar Set AN/MPQ-29

Three variations of design were developed for the global task of operating adjustments and four variations were developed for the global task of target acquisition and radar tracking. These variations are purely hypothetical and should not be construed as suggestions for changing the original system (Variation O). In some instances, the variations of design would lead to less effective systems, from the information transfer point-of-view, than the original design. The variations of design were developed to test the sensitivity of the DEI technique for this system.

The three design variations for the operating adjustments task are:

Variation 1 Place all unused controls and indicators behind covers. The covers could be easily opened by the operator if he wished access to these indicators and controls.

Variation 2 Combine the plan position indicator scope and the J scope into one scope. Remove all the J scope controls. Combine the azimuth and elevation handwheels into one control. The control will be similar to a joystick, where manipulating the stick to the right or left controls the azimuth position of the scanner and forward or backward manipulations control the elevation. Diagonal movement would cause variation in both azimuth and elevation. The left and right range slew thumbbuttons will now appear on this single control.

Variation 3 Substitute one digital voltmeter on the meter panel for the five meters presently on the panel. This will not involve the magnetron frequency indicator meter. The digital voltmeter will have a bank of four digits. All voltage checks and operating adjustments will be performed as they were in the original design. Similarly, the same controls will be used and in the same manner prescribed for the original design.

DEI Values for the Operating Adjustments Task

The details for the calculations of the DEI for each of the design variations and the original equipment design, along with the transfer chart for the original design, are presented in Appendix A to this report. The results of the DEI calculations for the original design (Variation O) and each of the hypothetical variations are summarized as Table 5.

Table 5

DEI Values for the Radar Set AN/MPQ-29
(Operating Adjustments Task)

	DEI(I')	$\Delta = I_i' - I_L$	$\frac{\Delta_i}{\Delta_{max}}$	Rank Order
Variation				
O	.00103	.00008	.04	3
1	.00280	.00185	1.00	1
2	.00104	.00009	.05	2
3	.00095	0	0	4

The highest ranked variation, Variation 1, removed many unused indicators and controls which were penalizing the DEI in Variation O by their presence. The improvement in information transfer realized as a result of this design variation rendered it the best of the four. Variation 2 and Variation O were almost equivalent in their DEI values, and Variation 4 was ranked as the poorest of the four designs.

Design Variations for Target Acquisition and Radar Tracking

The four variations of design for the Target Acquisition and Radar Tracking task were:

Variation 1 Place all unused controls and indicators behind covers. The covers could be easily opened by the operator if he wished access to these indicators and controls.

Variation 2 Combine the plan position indicator scope and the J scope into one scope. Remove all the J scope controls. Combine the azimuth and elevation handwheels into one control. The control will be similar to a joystick, where manipulating the stick to the right or left controls the azimuth position of the scanner and forward and backward manipulations control the elevation. Diagonal movement would cause variation in both azimuth and elevation. The left and right range slew thumbbuttons will now be combined into this single control.

Variation 3 Substitute one digital voltmeter on the meter panel for the five meters presently on the panel. This will not involve the magnetron frequency indicator meter. The digital voltmeter will have a bank of four digits. All voltage checks and operating adjustments will be performed as they were in the original design. Similarly, the same controls will be used and in the same manner prescribed for the original design.

Variation 4 To reduce or eliminate jamming on the J scope, place the anti-jam-normal-calibrate switch in the anti-jam position. All other adjustments will now be performed automatically.

DEI Values for the Target Acquisition and Radar Tracking Task

The DEI calculations for each of the four design variations and the original design, along with the transfer chart for the original design, Variation O, are presented in Appendix B. The results of the calculations are presented as Table 6.

As with the operation adjustments task, Variation 1 was ranked the highest by the DEI technique. This variation involved the removal of all unused indicators and controls.

Table 6

DEI Values for the Radar Set AN/MPQ-29
(Target Acquisition and Radar Tracking Task)

Variation	DEI(I')	$\Delta = I_i' - I_L$	$\frac{\Delta_i}{\Delta_{max}}$	Rank Order
O	.00139	0	0	5
1	.00295	.00156	1.00	1
2	.00152	.00013	.08	3
3	.00149	.00010	.06	4
4	.00188	.00049	.31	2

The fourth variation reduced the procedures involved in the process of eliminating jamming considerably. As a result, this variation ranked second out of the five. According to the DEI, for this task and from the points of view considered, each of the variations presented were improvements over the original system.

Radar Set AN/TPS-33

The AN/TPS-33 is a portable transmitter-receiver set used to search for, detect, and track moving targets on the ground. The set possesses a maximum range of 20,000 yards and can detect targets at any azimuth. Moving target detection involves both audio-frequency amplitude modulated signals which are received over the operator's headset and a visual, cathode ray tube display for a video display of targets. The auditory signals vary in frequency with speed, direction, and type of target. The experienced operator can distinguish between walking men and moving vehicles by the different types of sound each produces. Different types of vehicles will produce different tones.

The system is capable of automatic search through 360 degrees of azimuth and sector scanning. In sector scan, an area varying from 30 to 140 degrees can be selectively scanned. The operator can also follow a target in range and azimuth by adjusting the manual controls. The AN/TPS-33 control panels are shown in Figure 3.

The operator's tasks on this equipment have been analyzed in terms of two separate and distinct tasks. The first task involves those functions subsumed under the heading of starting, tuning, and orienting the equipment for operation; the second task involves those functions subsumed under the global heading of target detection. The former task includes all the subtasks involved in starting, adjusting, and readying the equipment for operation. The latter task, target detection, involves the actual tactical operation of the equipment for locating and tracking moving targets on the ground.

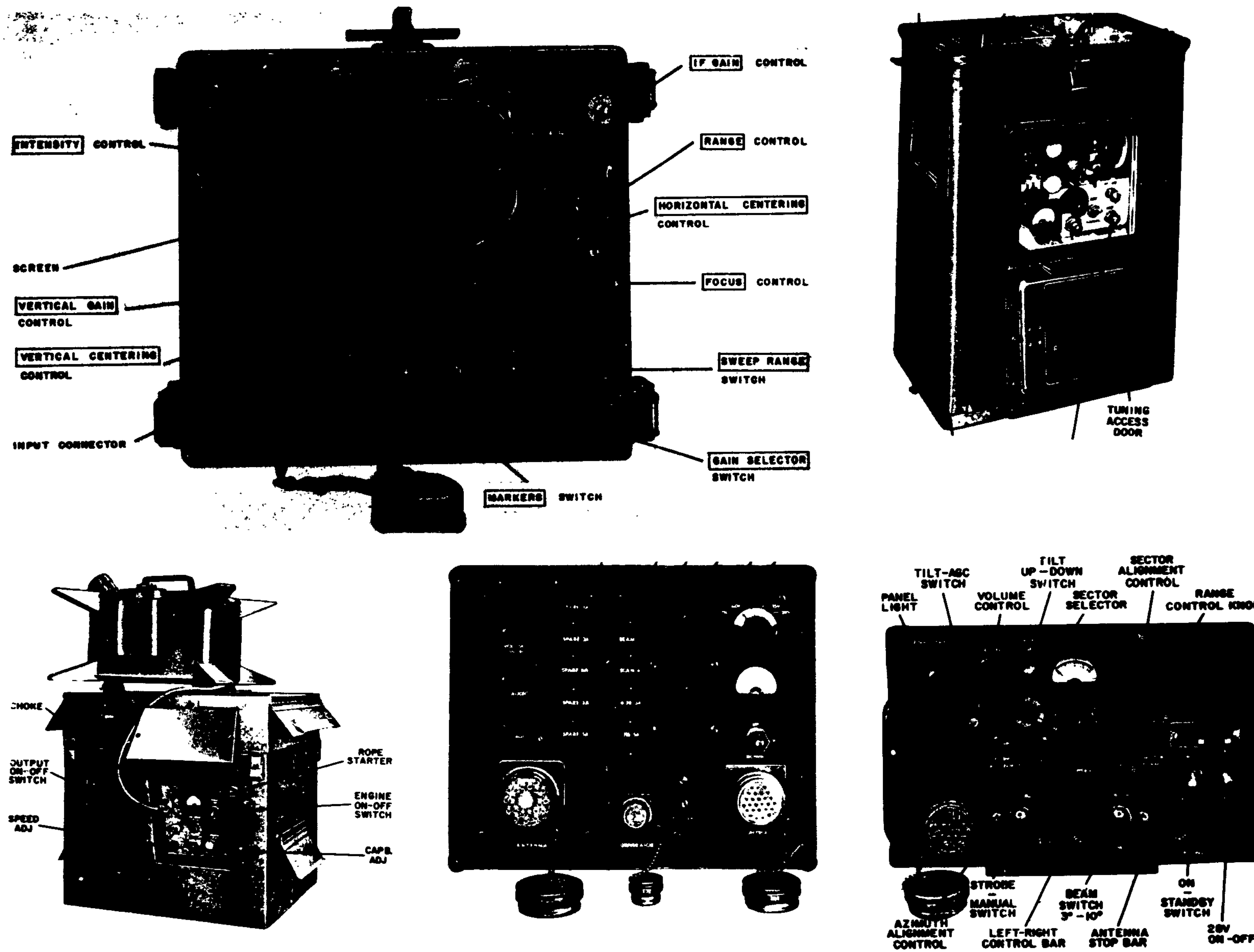

Figure 3 Radar Set AN/TPS-33

Four variations of design were developed for the radar set AN/TPS-33. The same variations are used for both the starting, tuning, and orienting equipment task and for the target detection task. These variations are:

Variation 1 Remove the antenna stop bar on the control indicator. Combine the strobe-manual switch and the left-right control bar into one handwheel. When the handwheel is at its normal position, the radar will scan automatically; when the handwheel is depressed, scanning will be under manual control. Rotating the handwheel will allow manual search.

Variation 2 Remove all meters from the panels (this involves four meters) and substitute three differently colored lights which when lighted will provide the same information as was obtained from the meters. Only one can be lighted at any one time.

Variation 3 Combine the range and azimuth controls on the control indicator into one joystick type control. Pushing the joystick forward and backward will control the range at which the radar is searching. Pushing the joystick sideways from left to right controls the azimuth. Diagonal movements would result in both range and azimuth modification.

Variation 4 Remove the following controls from the control indicator: antenna stop bar, 3° - 10° beam switch, and left-right control bar. Instead of the two position strobe-manual switch, a target reject pushbutton will be included. The antenna will automatically scan an area and lock on the nearest moving target. The beam is automatically narrowed and the range and azimuth of the moving target is automatically indicated on their respective indicators. After target evaluation, the operator continues scanning and moves on to the next target by pushing a target reject pushbutton.

DEI Values for the Starting, Tuning, and Orienting Equipment Task

The detailed DEI calculations for each design variation for the starting, tuning, and equipment orientation task are presented in Appendix C.

The results of the DEI calculations are presented as Table 7. Variation 4 had the highest DEI value and therefore is ranked first by the DEI in the hierarchy of design variations. This variation improved the information transfer of the system by removing three controls, five links, and one element. Since the starting, tuning, and orienting equipment task did not include detection of targets, the second aspect of Variation 4, that of automatically detecting and tracking the target, did not affect the DEI value for this task. Variation 2 was ranked as the poorest design variation of the five primarily because of the increased information mismatch incorporated into this design by the included light indicators. The links emanating from these indicators often terminate in three state controls, thus creating the mismatch. To increase the match in the system, the controls linked to the indicators by forward links would have to be modified to the same degree as the indicators.

Table 7

DEI Values for the Radar Set AN/TPS-33 (Starting, Tuning, and Orienting Equipment Task)

	DEI(I')	$\Delta = I'_i - I_L$	$\frac{\Delta_i}{\Delta_{max}}$	Rank Order
Variation				
O	.000672	.000077	.39	3
1	.000699	.000104	.53	2
2	.000595	0	0	5
3	.000597	.000002	.01	4
4	.000792	.000197	1.00	1

DEI Values for the Detection of Targets Task

The transfer chart and the DEI calculations for the target detection task are presented in Appendix D. The results of the DEI calculations are presented in Table 8.

Table 8

DEI Values for the Radar Set AN/TPS-33 (Target Detection Task)

	DEI(I')	$\Delta = I'_i - I_L$	$\frac{\Delta_i}{\Delta_{max}}$	Rank Order
Variation				
O	.00310	.00027	.15	4
1	.00343	.00060	.33	2
2	.00311	.00028	.16	3
3	.00283	0	0	5
4	.00463	.00180	1.00	1

Here, as in the previous analysis of the AN/TPS-33, the fourth variation was ranked first. In addition to removing certain controls, the subtask of detecting and tracking targets was made automatic. This unloaded the equipment operator considerably.

Variation 3, which might on the surface appear to represent an information transfer improvement, suffers because of a lack of compatibility between information presented and response requirements. Hence, the DEI is made lower and therefore the design is evaluated as being of less merit in the display reading→operator decision making→control action context.

Review of DEI Applications

In the course of the present program, the DEI technique has been applied to a total of 58 real and hypothetical systems. The DEI has continuously displayed its sensitivity in quantitatively distinguishing among design variations of a system from the point of view of the information transfer required in order to meet the goals of the system. This always involves the information included in individual display reading→operator decision making→control action links.

FACTUAL DATA V

VALIDITY

Preliminary validity measures of the DEI technique were obtained on several Signal Corps' systems and their variations and were reported in the fourth quarterly report of this series (Siegel, Miehle, and Federman, 1962). However, subsequent to that verification, the DEI was revised and expanded. Accordingly, an additional validational study seemed warranted.

Four prominent men in the fields of human factors and information theory were asked to evaluate various systems and hypothetical variations of these systems (Radio Set AN/GRC-50, Radio Set AN/GRC-66, Radar Set AN/MPQ-29 [Operating Adjustments Task], Radar Set AN/MPQ-29 [Target Acquisition and Radar Tracking Task], Radar Set AN/TPS-33 [Starting, Tuning, and Orienting Equipment Task], and Radar Set AN/TPS-33 [Detection of Targets Task]). The four authorities involved are all recognized men in their fields. Three are psychologists and one is an engineer. The authorities were assembled in a conference, at which time the systems were explained. They were then requested to rank the systems along a ten centimeter rating scale in terms of system adeptness for information transfer.

In rating each system and its variations, the judges were first thoroughly familiarized with the operation of the equipment under consideration, along with the design details of its various indicators, controls, and required control actions. The task of the judges was to "...indicate the relative ratings

of the variations of design described. Your judgment should be based on the effectiveness of the design for allowing the operator to accomplish conversion and transfer of information into relevant actions for the tasks. After studying the variations of design, select the variation which you feel most effective and place its number above the point marked "HIGHEST" on the rating scale. Then select the variation which you feel is least effective and place its number over the point marked "LOWEST." Mark the points on the line corresponding to the remaining variations in accordance with your rating of their relative effectiveness. Place the number of the variations above the points you mark. The distance between two points should be in proportion to the corresponding difference in effectiveness. If two or more variations are judged equally effective, mark their numbers above the same point."

The individual ratings on this scale were averaged for each system and the systems ranked hierarchically. Spearman rank order coefficients of correlation between these data and the ranked data obtained from the application of the DEI technique were obtained. The correlations are presented as Table 9.

Table 9

Rank Order Correlations Between Authorities' Mean Ranks and the DEIs

System and Variations	Correlation
Radio Set AN/GRC-60	.68
Radio Set AN/GRC-66	.82
Radar Set AN/MPQ-29 (Operating Adjustments)	.80
Radar Set AN/MPQ-29 (Target Acquisition and Radar Tracking)	.60
Radar Set AN/TPS-33 (Starting, Tuning, and Orienting Equipment)	.68
Radar Set AN/TPS-33 (Target Detection)	.70

Table 9 indicates relatively high and acceptable agreement between the DEI calculations and the criteria. On the basis of these validity coefficients, the contention that the DEI technique possesses merit for achieving its purpose gains additional support. This validity study and the previous one, reported in the fourth quarterly, both suggest that the purported purpose of developing a technique for evaluating the effectiveness of displays in systems to transfer information to an operator and for the operator to act on the information has been, to some extent achieved.

Agreement Among Authorities

There is always the possibility of some variation or inconsistency among the opinions of experts on the merit of a particular equipment design. Various experts may tend to emphasize different equipment design features as important or non-important on the basis of their individual experiences. Moreover, when a number of equipment design features are simultaneously varied, it is difficult for any person to weight appropriately the design variations in terms of their importance to the task of the system and to synthesize appropriately the weighted composite into an over-all design recommendation.

Intraclass coefficients of correlation were obtained on the authorities' ranked order of the variations for each system. The correlation coefficients, as presented in Table 10, denote moderate agreement among the raters' evaluations of the effectiveness of the variations in each system studied.

Table 10

Intraclass Coefficients of Correlation Among Authorities

System	Correlation	P
Radio Set AN/GRC-50	.25	-
Radio Set AN/GRC-66	.27	-
Radar Set AN/MPQ-29 (Operating Adjustments)	.41	.05
Radar Set AN/MPQ-29 (Target Acquisition and Radar Tracking)	.30	-
Radar Set AN/TPS-33 (Starting, Tuning, and Orienting Equipment)	.69	.01
Radar Set AN/TPS-33 (Detection of Targets)	.69	.01

The, at best, moderate agreement among judges is not a surprising result. In one sense, it may be maintained that the DEI technique agreed with the mean expert opinion better than the experts agreed with each other.

Correlations Between the DEI and the Individual Authorities

Rank order correlations were obtained between the individual authority's evaluations of the systems and the DEI. These correlational measures are presented in Table 11. The correlation coefficients indicate that in all but a few instances a positive relationship existed between the opinions of the individual authorities and the results of the DEI technique.

Table 11

Rank Order Correlations Between the Individual Judges and the DEI

Judge	Radio Set AN/GRC-50	Radio Set AN/GRC-66	Radar Set AN/MPQ-20 (Operating Adjustments)	Radar Set AN/MPQ-20 (Target Acquisition and Radar Tracking)	Radar Set AN/TPS-33 (Starting, Tuning, and Orienting Equipment)	Radar Set AN/TPS-33 (Detection of Targets)
1	.68	.08	.20	.40	1.00	.65
2	.58	.98	.68	.88	.80	.68
3	.38	.38	.10	-.10	.40	.60
4	-.02	.75	.50	.80	.75	.62

CONCLUSIONS

The preceding sections of this quarterly report suggest short computational methods for obtaining the DEI. One such method is a general computational method which eliminates the calculations necessary for obtaining the factors of the DEI. This method provides an approximate rather than an exact DEI value and is similar to linear interpolation. Another computational approach, the fractional incremental method, can be used for obtaining relative DEIs. These values are exact rather than approximate. The method is recommended when there are only two or three variations of design and when the increments are known.

It may be advantageous in certain instances to use a computer for calculating DEIs. A computer procedure for calculating DEIs is outlined. Thus, the calculations of the DEIs have been extended and developed into three new methods which can be applied and used with relative ease by systems analysts.

The revised DEI was applied to several new systems and their variations. The DEI displayed its evaluative sensitivity for distinguishing between variations of equipment designs.

The validity study reported suggested that the DEI correlated within acceptable limits with the criterion employed.

PROGRAM FOR NEXT INTERVAL

During the next interval, a final report which summarizes the total DEI developmental program will be prepared.

Additionally, in accordance with purpose 8 of the current program, an experiment will be carried out comparing the information transfer effectiveness of visual, auditory, and electrocutaneous displays, as well as various combinations of these information presentation modes.

REFERENCES

Siegel, A., Miehle, W., and Federman, P. Information transfer in display-control systems. (Fourth Quarterly Report). Wayne, Pa.: Applied Psychological Services, 1962.

APPENDICES

APPENDIX A

1. Transfer Chart for the Original Design of the Radar Set AN/MPQ-29 (Operating Adjustments Task)

2. DEI Calculations for the Radar Set AN/MPQ-29 (Operating Adjustments Task)

$$DEI = APS$$

where

$$A = \frac{1}{(1 + \Sigma w)}$$

$$P = \frac{(n + m)_u}{\sqrt{N(n + m)_t (Q + n_0)}}$$

$$S = \sqrt[4]{R} \; \exp \left\{ - \frac{1}{4} \left[\Sigma I \left(\frac{T}{T'} - 1\right) + \frac{1}{16} \Sigma I \left(\frac{T}{T'}\right)^3 + \frac{N_c}{10} + \Sigma |M| \right] \right\}$$

Explanations for the various symbols were given on page 4.

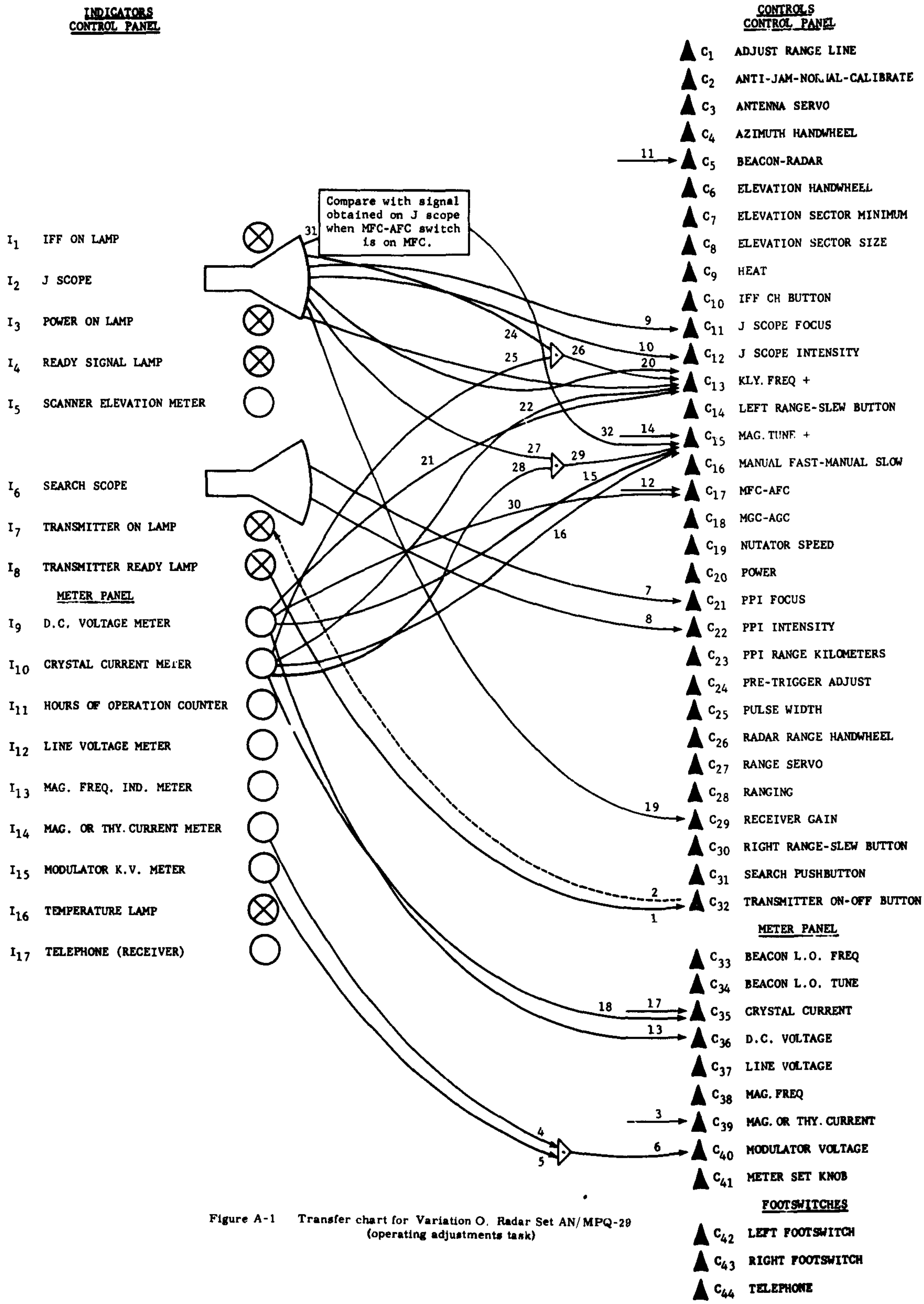

Figure A-1 Transfer chart for Variation O. Radar Set AN/MPQ-29 (operating adjustments task)

Variation O

Factor A There are 11 forward links carrying a weight of 2 (links 4, 5, 13, 15, 18, 21, 22, 25, 28, 30, 31), 17 forward links with a weight of 1 (links 1, 3, 7, 8, 9, 10, 11, 12, 14, 16, 17, 19, 20, 23, 24, 27, 32), one corroborative link with a weight of .5 (link 2), 3 links with zero weight (link 6, 26, 29), and one box with a weight of 4.

$$1 + \Sigma w_i = 1 + 43.5 = 44.5$$

Factor P There are 7 indicators and 14 controls used, 31 forward links, a total of 61 indicators and controls, 62 actual indicator and control parts, and 4 other elements.

$$(n + m)_u = 21$$

$$\sqrt{N(n + m)_t(Q + n_0)} = \sqrt{31(61)(62 + 4)} = \sqrt{124806} = 353.28$$

Factor S There is a mismatch of 1.041 digits.

$$\frac{1}{4} e^{-1.041} = e^{-.26} = .771$$

$$\text{DEI} = \frac{21(.771)}{44.5(353.28)} = .00103$$

Variation 1

Factor A Same as Variation O.

Factor P There are now a total of 21 indicators and controls and 22 actual indicator and control parts.

$$(n + m)_u = 21$$

$$\sqrt{N(n + m)_t(Q + n_0)} = \sqrt{31(21)(22 + 4)} = 130.10$$

Factor S Same as Variation O.

$$\text{DEI} = \frac{21(.771)}{44.5(130.10)} = .00280$$

Variation 2

Factor A Links 9 and 10 are eliminated. Therefore:

$$1 + \Sigma w_i = 1 + 41.5 = 42.5$$

Factor P There are 18 used indicators and controls, 19 forward links, a total of 56 indicators and controls, 57 actual indicator and control parts, and 4 other elements.

$$(n + m)_u = 18$$

$$\sqrt{N(n + m)_t(Q + n_0)} = \sqrt{29(56)(57 + 4)} = 314.74$$

Factor S Same as Variation O.

$$DEI = \frac{18(.771)}{42.5(314.74)} = .00104$$

Variation 3

Factor A Links 5 and 6 are eliminated. Thus:

$$1 + \Sigma w_i = 1 + 41.5 = 42.5$$

Factor P There are 18 used indicators and controls, 34 forward links, a total of 57 indicators and controls, 58 actual indicator and control parts, and 3 other elements.

$$(n + m)_u = 18$$

$$\sqrt{N(n + m)_t(Q + n_0)} = \sqrt{34(57)(58 + 3)} = 343.83$$

Factor S Same as Variation O.

$$DEI = \frac{18(.771)}{42.5(343.83)} = .00095$$

APPENDIX B

1. Transfer Chart for the Original Design of the Radar Set AN/MPQ-29 (Target Acquisition and Radar Tracking Task)

2. DEI Calculations for the Radar Set AN/MPQ-29 (Target Acquisition and Radar Tracking Task)

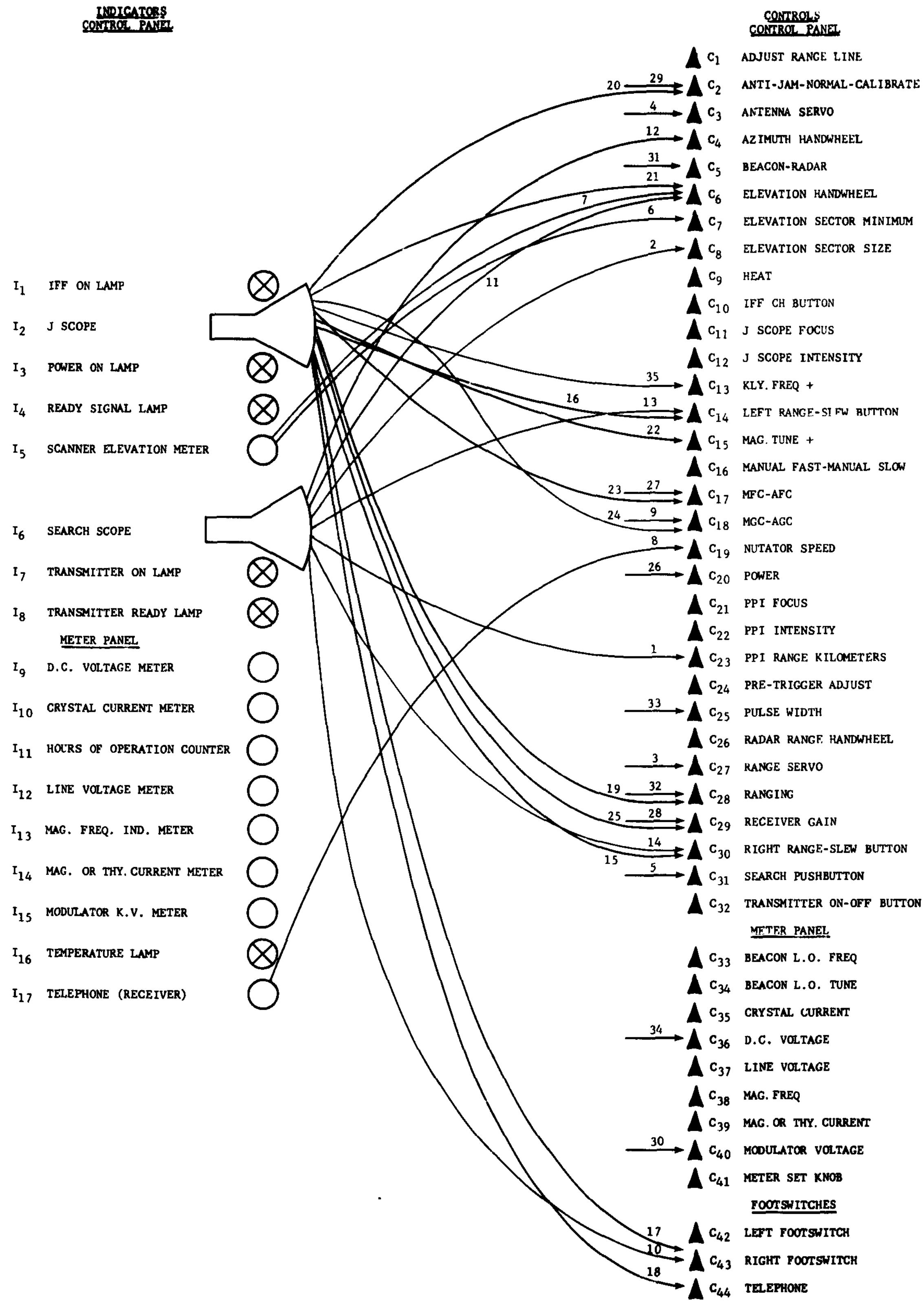

Figure B-1 Transfer chart for Variation O. Radar Set AN/MPQ-29 (target acquisition and radar tracking task)

Variation O

Factor A There are 10 forward links carrying a weight of 2 (links 1, 2, 6, 7, 13, 14, 15, 16, 17, 21), and the remaining 25 links are forward links each having a weight of 1.

$$1 + \Sigma w_i = 1 + 45 = 46$$

Factor P There are 4 indicators and 25 controls used, 35 forward links, a total of 61 indicators and controls, and 62 actual indicator and control parts.

$$(n + m)_u = 29$$

$$\sqrt{N(n + m)_t(Q + n_0)} = \sqrt{35(61)(62 + 0)} = 363.83$$

Factor S There is a mismatch of .88 digits.

$$\frac{1}{4} e^{-.88} = e^{-.22} = .803$$

$$\text{DEI} = \frac{29(.803)}{46(363.83)} = .00139$$

Variation 1

Factor A Same as Variation O.

Factor P There are now a total of 29 indicators and controls and 29 actual indicator and control parts.

$$(n + m)_u = 29$$

$$\sqrt{N(n + m)_t(Q + n_0)} = \sqrt{35(29)(29 + 0)} = 171.57$$

Factor S Same as Variation O.

$$DEI = \frac{29(.803)}{46(171.57)} = .00295$$

Variation 2

<u>Factor A</u> Links 12 and 21 are eliminated and link 11 gets a weight of 2 instead of 1.

$$1 + \Sigma w_i = 1 + 43 = 44$$

<u>Factor P</u> There are 27 indicators and controls, 33 forward links, a total of 56 indicators and controls, and 57 actual indicator and control parts.

$$(n + m)_u = 27$$

$$\sqrt{N(n + m)_t(Q + n_0)} = \sqrt{33(56)(57 + 0)} = 324.56$$

<u>Factor S</u> Same as Variation O.

$$DEI = \frac{27(.803)}{44(324.56)} = .00152$$

Variation 3

Factor A Same as Variation O.

Factor P There are 29 used indicators and controls, 35 forward links, a total of 57 indicators and controls, and 58 actual indicator and control parts.

$$(n + m)_u = 29$$

$$\sqrt{N(n + m)_t(Q + n_0)} = \sqrt{35(57)(58 + 0)} = 340.16$$

Factor S Same as Variation O.

$$DEI = \frac{29(.803)}{46(340.16)} = .00149$$

Variation 4

Factor A Seven forward links are removed with a total weight of 8.

$$1 + \Sigma w_i = 1 + 37 = 38$$

Factor P There are 29 used indicators and controls, 28 forward links, a total of 61 indicators and controls, and 62 actual indicator and control parts.

$$(n + m)_u = 29$$

$$\sqrt{N(n + m)_t (Q + n_0)} = \sqrt{28(61)(62 + 0)} = 325.42$$

Factor S Same as Variation O.

$$DEI = \frac{29(.803)}{38(325.42)} = .00188$$

APPENDIX C

1. Transfer Chart for the Original Design of the Radar Set AN/TPS-33 (Starting, Tuning, and Operating Equipment Task)

2. DEI Calculations for the Radar Set AN/TPS-33 (Starting, Tuning, and Operating Equipment Task)

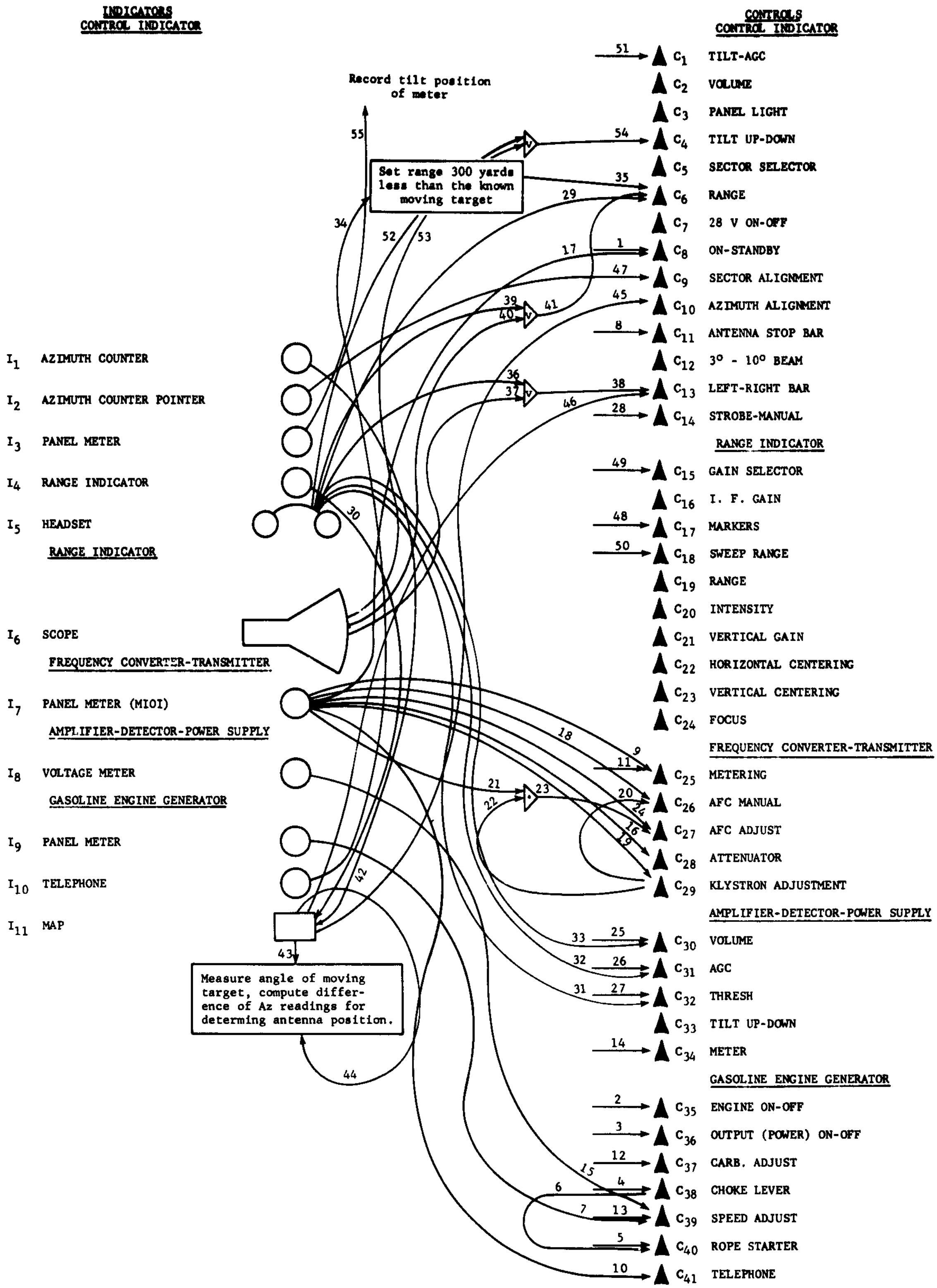

Figure C-1 Transfer chart for Variation O Radar Set AN TPS-33 (starting tuning and orienting equipment task)

Variation O

Factor A There are 17 forward links with weights of 2 (links 7, 9, 10, 11, 14, 15, 16, 17, 18, 19, 21, 24, 30, 42, 43, 45, 46), 28 forward links with weight of 1 (links 1, 2, 3, 4, 5, 6, 8, 12, 13, 20, 22, 25, 26, 27, 28, 29, 31, 32, 33, 34, 35, 44, 47, 48, 49, 50, 51, 55), 10 links with zero weights (links 23, 36, 37, 38, 39, 40, 41, 52, 53, 54), and 2 boxes.

$$1 + \Sigma w_i = 1 + 70 = 71$$

Factor P There are 39 used indicators and controls, 55 forward links, a total of 52 indicators and controls, 52 actual indicator and control parts, and 6 other elements.

$$(n + m)_u = 39$$

$$\sqrt{N(n + m)_t(Q + n_0)} = \sqrt{55(52)(52 + 6)} = 407.28$$

Factor S There is a mismatch of 2.788 digits.

$$\frac{1}{4} e^{-2.788} = e^{-.697} = .498$$

$$DEI = \frac{39(.498)}{72(407.28)} = .000672$$

Variation 1

Factor A Link 8 is removed. Therefore:

$$1 + \Sigma w_i = 1 + 69 = 70$$

Factor P There are 37 used indicators and controls, 54 forward links, a total of 50 indicators and controls, a total of 50 actual indicator and control parts, and 6 other elements.

$$(n + m)_u = 37$$

$$\sqrt{N(n + m)_t(Q + n_0)} = \sqrt{54(50)(50 + 6)} = 388.84$$

Factor S The mismatch for link 31 is changed from .301 to .176. Therefore:

$$\frac{1}{4} e^{-2.663} = e^{-.666} = .514$$

$$\text{DEI} = \frac{37(.514)}{70(388.84)} = .000699$$

Variation 2

<u>Factor A</u> Same as Variation O.

<u>Factor P</u> There are 36 used indicators and controls, 54 forward links, a total of 49 indicators and controls, 51 actual indicator and control parts, and 6 other elements.

$$(n + m)_u = 36$$

$$\sqrt{N(n + m)_t(Q + n_0)} = \sqrt{54(49)(51 + 6)} = 388.36$$

<u>Factor S</u> The mismatch is increased from 2.788 in Variation O to 3.140 as a result of links 7, 9, 15, 16, 17, 18, 19, 23, 24.

$$\frac{1}{4} e^{-3.140} = e^{-.785} = .456$$

$$\text{DEI} = \frac{36(.456)}{71(388.36)} = .000595$$

Variation 3

Factor A Same as Variation O.

Factor P There are 38 used indicators and controls, 55 forward links, a total of 51 indicators and controls, 51 actual indicator and control parts, and 6 other elements.

$$(n + m)_u = 38$$

$$\sqrt{N(n + m)_t(Q + n_0)} = \sqrt{55(51)(51 + 6)} = 399.86$$

Factor S This mismatch is increased from 2.788 in Variation O to 3.232 as a result of links 29 and 41.

$$\frac{1}{4} e^{-3.232} = e^{-.808} = .446$$

$$\text{DEI} = \frac{38(.446)}{71(399.86)} = .000597$$

Variation 4

Factor A Links 8, 36, 37, 38, and 46 are removed. Therefore:

$$1 + \Sigma w_i = 1 + 68 = 69$$

Factor P There are 37 used indicators and controls, 50 forward links, a total of 49 indicators and controls, 49 actual indicator and control parts, and 5 other elements.

$$(n + m)_u = 37$$

$$\sqrt{N(n + m)_t(Q + n_0)} = \sqrt{50(49)(49 + 5)} = 363.73$$

Factor S The mismatch is decreased from 2.788 in Variation O to 2.487 as a result of link 38.

$$\frac{1}{4} e^{-2.487} = e^{-.622} = .537$$

$$\text{DEI} = \frac{37(.537)}{69(363.73)} = .000792$$

APPENDIX D

1. Transfer Chart for the Original Design of the Radar Set AN/TPS-33 (Detection of Targets Task)

2. DEI Calculations for the Radar Set AN/TPS-33 (Detection of Targets Task)

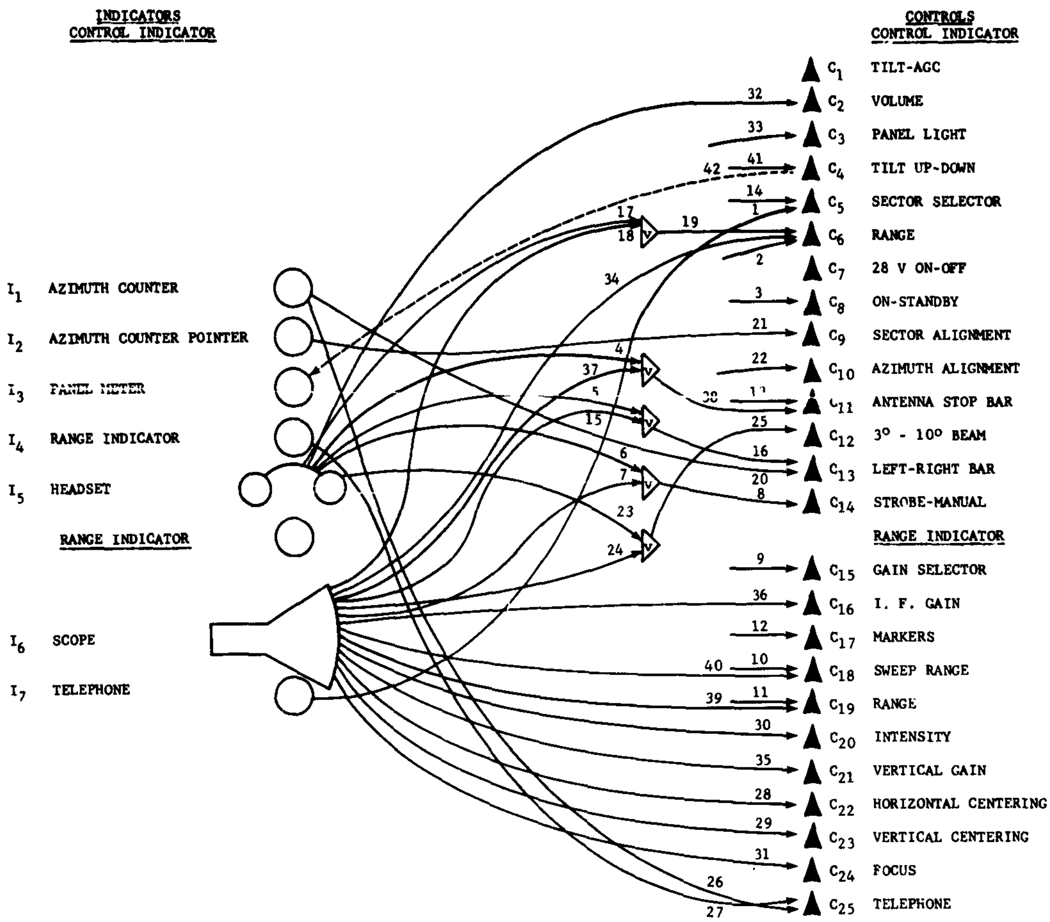

Figure D-1 Transfer chart for Variation O Radar Set AN/TPS-33
(detection of targets task)

Variation O

Factor A There are 6 double weighted links (links 1, 2, 14, 20, 26, 27), 20 single weighted links (links 3, 9, 10, 11, 12, 13, 21, 22, 28, 29, 30, 31, 32, 33, 34, 35, 36, 39, 40, 41), one corroborative link with a weight of .5 (link 42), and 15 zero weighted links (links 4, 5, 6, 7, 8, 15, 16, 17, 18, 19, 23, 24, 25, 37, 38).

$$1 + \Sigma w_i = 1 + 32.5 = 33.5$$

Factor P There are 29 used indicators and controls, 41 forward links, a total of 32 indicators and controls, 32 actual indicator and control parts, and 5 other elements.

$$(n + m)_u = 29$$

$$\sqrt{N(n + m)_t(Q + n_0)} = \sqrt{41(32)(32 + 5)} = 220.33$$

Factor S There is a mismatch of .954 digits.

$$\frac{1}{4} e^{-.954} = e^{-.238} = .788$$

$$\text{DEI} = \frac{29(.788)}{33.5(220.33)} = .00310$$

Variation O

Factor A There are 6 double weighted links (links 1, 2, 14, 20, 26, 27), 20 single weighted links (links 3, 9, 10, 11, 12, 13, 21, 22, 28, 29, 30, 31, 32, 33, 34, 35, 36, 39, 40, 41), one corroborative link with a weight of .5 (link 42), and 15 zero weighted links (links 4, 5, 6, 7, 8, 15, 16, 17, 18, 19, 23, 24, 25, 37, 38).

$$1 + \Sigma w_i = 1 + 32.5 = 33.5$$

Factor P There are 29 used indicators and controls, 41 forward links, a total of 32 indicators and controls, 32 actual indicator and control parts, and 5 other elements.

$$(n + m)_u = 29$$

$$\sqrt{N(n + m)_t(Q + n_0)} = \sqrt{41(32)(32 + 5)} = 220.33$$

Factor S There is a mismatch of .954 digits.

$$\frac{1}{4} e^{-.954} = e^{-.238} = .788$$

$$\text{DEI} = \frac{29(.788)}{33.5(220.33)} = .00310$$

Variation 1

Factor A Links 4, 13, 37, and 38 are moved. Therefore:

$$1 + \Sigma w_i = 1 + 31.5 = 32.5$$

Factor P There are 27 used indicators and controls, 37 forward links, a total of 30 indicators and controls, 30 actual indicator and control parts, and 4 other elements.

$$(n + m)_u = 27$$

$$\sqrt{N(n + m)_t(Q + n_0)} = \sqrt{37(30)(30 + 4)} = 194.27$$

Factor S The mismatches for links 16 and 20 are increased by .250 digits and the mismatch for link 8 is decreased by .176 digits, giving a total mismatch increase of .074.

$$\frac{1}{4} e^{-.880} = e^{-.220} = .803$$

$$\text{DEI} = \frac{27(.803)}{32.5(194.27)} = .00343$$

Variation 2

<u>Factor A</u> Link 42 is removed. Therefore:

$$1 + \Sigma w_i = 1 + 32 = 33$$

<u>Factor P</u> There are 29 used indicators and controls, 41 forward links, a total of 31 indicators and controls, 43 actual indicator and control parts, and 5 other elements.

$$(n + m)_u = 29$$

$$\sqrt{N(n + m)_t(Q + n_0)} = \sqrt{41(31)(34 + 5)} = 222.64$$

<u>Factor S</u> Same as Variation O.

$$DEI = \frac{29(.788)}{33(222.64)} = .00311$$

Variation 3

Factor A The weight of link 22 is increased from 1 to 2.

$$1 + \Sigma w_i = 1 + 33.5 = 34.5$$

Factor P There are 28 used indicators and controls, 41 forward links, a total of 31 indicators and controls, 31 active indicator and control parts, and 5 other elements.

$$(n + m)_u = 28$$

$$\sqrt{N(n + m)_t(Q + n_0)} = \sqrt{41(31)(31 + 5)} = 213.91$$

Factor S The mismatch for link 19 is increased by .222 digits.

$$\frac{1}{4} e^{-1.176} = e^{-.294} = .745$$

$$\text{DEI} = \frac{28(.745)}{34.5(213.91)} = .00283$$

Variation 4

Factor A Links 4, 5, 6, 7, 8, 13, 15, 16, 20, 23, 24, 25, 37, and 38 are removed for a total weight of 3; a single weight link is included from the telephone to the target reject control.

$$1 + \Sigma w_i = 1 + 30.5 = 31.5$$

Factor P There are a total of 26 used indicators and controls, 28 forward links, a total of 29 indicators and controls, 29 actual indicator and control parts, and 1 other element.

$$(n + m)_u = 26$$

$$\sqrt{N(n + m)_t(Q + n_0)} = \sqrt{28(29)(29 + 1)} = 156.08$$

Factor S Links 16 and 20 were eliminated. Therefore:

$$\frac{1}{4} e^{-.528} = e^{-.132} = .876$$

$$\text{DEI} = \frac{26(.876)}{31.5(156.08)} = .00463$$

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A. I. Siegel, W. Miehle, and P. Federman

Seventh Quarterly Progress Report
16 December 1962 - 15 March 1963
DA 36-039 SC-87230, Project No. 3A95-20-001

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